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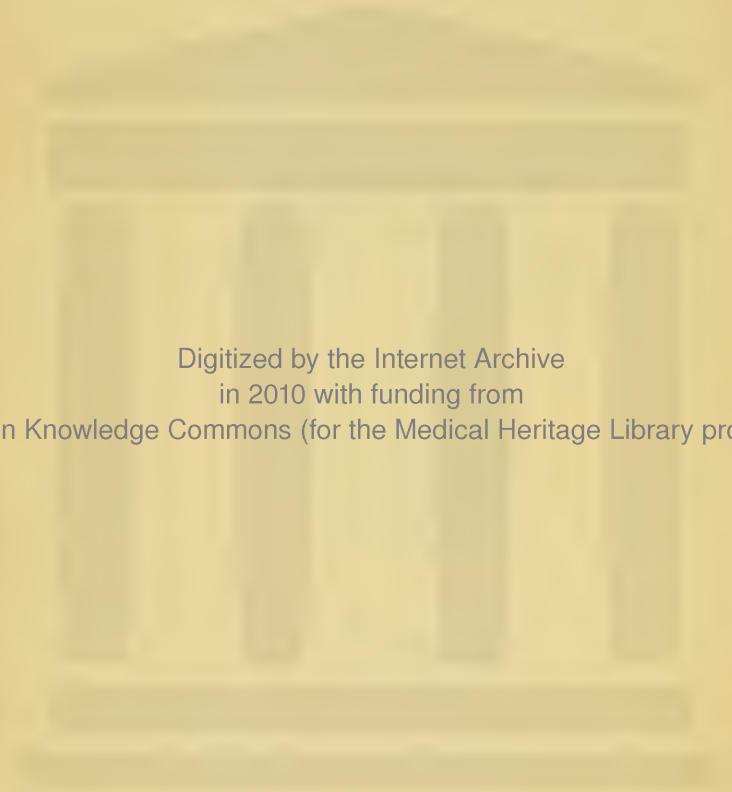

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WHAT CAUSES FATIGUE?

AN ADDRESS

BY THOMAS DARLINGTON, M.D.

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NEW YORK

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WHAT CAUSES FATIGUE?

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In modern industry there is no question of more importance, so far as human activity is concerned, than that of bodily fatigue. A review of the causes of fatigue and of remedial measures looking to prevention of over-tiredness is therefore appropriate at this meeting.

It needs no scientist to tell us that the proper use of muscle increases its power for work, that proper exercise increases strength. As Josephine Goldmark has well said:

Work itself is of the essence of life; without it, man's physical as well as his moral nature decays. Regular continuous labor and exertion is as necessary for the worker's health as it is for subsistence.

SOME PHYSIOLOGICAL FACTS.

To understand fatigue, and the various factors of its causation, we must understand certain physiological facts. In the living body there is constant change. Constantly there is a building up process; constantly there is a breaking down and wasting process. Even though there be but little bodily movement or exertion, still the glands are secreting, still there is production of heat. The chemical changes that take place are known as metabolism, the building up process being called anabolism, and the breaking down process catabolism.

In the muscles particularly such chemical changes are constantly taking place. These changes take place more rapidly when the muscles are in action, that is, when the muscles contract. Every exertion and muscular contraction causes the expenditure of energy. Every muscle contains in itself latent energy in fuel to be converted into mechanical energy and heat. This fuel is supplied from the blood and is in the form of sugar (dextrose $C_6H_{12}O_6$), animal starch (glycogen $C_6H_{10}O_5$), and fat.

The living substance of muscle has the power of burning up sugar. In this process lactic acid and ultimately carbon dioxide and water are formed. Thus, dextrose changes to lactic acid—$C_6H_{12}O_6$ (dextrose) = 2 ($C_3H_6O_3$) (lactic acid) — and the lactic acid is finally broken down into carbon dioxide and water.

Muscle is made to contract by stimulation. This stimulation is through impulse, from the brain or other parts of the nervous system. It may primarily arise from the will, and secondarily from heat, from cold, from electricity or from other causes. When a muscle contracts more oxygen is used and more carbon dioxide is discharged than when it is resting. A normal resting muscle is alkaline in its reaction, but after a number of rapid contractions it becomes acid in its reaction.

The materials for building up the tissues are carried to the various portions of the body by the blood stream, and the products of waste are carried away from the tissues by the same means.

The oxygen necessary for combustion—that is, for chemical transformation in the production of energy—is carried by the red material in the blood (hæmoglobin) to the tissues. The red material there gives off some of its oxygen, and the blood takes up carbon dioxide, which it carries back to the lungs to be eliminated.

The liver normally forms sugar and glycogen, or animal starch, a substance readily converted into sugar. Muscle tissue is capable of storing up in the form of glycogen much of the sugar brought to it. Glycogen is, therefore, a normal constituent of the muscles.

In some respects the development of energy in the body is analogous to the development of steam in a boiler or the operation of a gas engine. There must be fuel, such as coal, oil or gas; there must be a supply of air containing oxygen; and there are the ashes as waste.

From the above it is obvious that muscular energy depends largely upon three things:

1. The amount of fuel stored and the ability of the system to bring it into use.

2. The ability of the system to furnish oxygen to burn the fuel.

3. The ability of the system to carry off waste or other toxic substances.

Conversely, fatigue is due primarily to the failure of the system to perform properly one or more of these functions.

Storage of Fuel.

First, fatigue may be caused by anything that interferes with the storage of fuel. This may arise from a lack of fuel. Under this head would come underfeeding, improper feeding, indigestion of food, lack of assimilation of food, and incapacity of the liver and muscles to store sufficient glycogen.

It requires no argument to prove that if fuel is lacking energy must also be lacking. So if one does not have sufficient food, he cannot store enough energy. This may also be the case when a large enough quantity is eaten but not of the proper kind or quality. One has learned much who has learned what food to purchase. For example, cabbage is a very common article of diet but there is little energy to be derived from it. We should all study food values and how and what to purchase in order to get the most and the best for our money.

It is impossible in this paper to go into all the details of the digestibility of different foods.

To regulate the food according to the demands of the body, to have a properly balanced dietary, comes only as the result of study. Education along these lines in connection with industrial plants is best given in the form of household instruction by trained nurses or domestic educators.

True, since Knoop has shown that the system can change one food into another, an excess of one kind of food is probably converted in the system into others. But physiological tests have shown that a mixed diet is best for the needs of the system. The body is very adaptable but we should not put upon it unnecessary alimentary burdens.

Pavlov has shown that the secretion of the gastric juice depends largely on the character of food and on appetite.

All of these things relate to the question of the wise

selection of food for energy and the needs of the system. An examination of many lunch buckets has indicated to me that sometimes but little thought is given as to the kind of food that goes into them, provided there is quantity. Many times the food in lunch buckets, such as yeast bread, becomes sweated, and milk in the coffee undergoes more or less fermentation. This bears directly upon energy.

After food reaches the stomach there is often much needless waste, particularly of the sugars, due to fermentation in the stomach. The sugars are split into acids before reaching the tissues and so are partly lost for energy. The fermentation is due to two causes: First, to a lack of gastric juice; and second, to an excess of bacteria. A lack of gastric juice, and therefore indigestion, is due to an improper selection of food, to a disturbed mental condition (anger, grief, worry) or to reflex disturbances of the gastric nerves, from chronic appendicitis, etc. Or there may be an excess of bacteria. This is due either to fermented or putrid foods, or to the addition of bacteria to the food from unclean mouths and bad teeth or dirty hands. Over-eating and rapidity of eating also affect digestion and therefore promote fatigue.

Assimilation of food varies in different persons. The capacity of the liver or of the muscles to store glycogen must depend somewhat on their size and the size of a muscle depends largely upon its use.

To combat fatigue from these causes it would be well to have at plants dining rooms and restaurants, with freshly and properly prepared and well selected foods, furnished at the lowest practicable price, served under cheerful and pleasant surroundings, and with sufficient time to eat.

A Lack of Oxygen Causes Fatigue.

Secondly, fatigue is caused by anything that interferes with the carrying of oxygen to the tissues. This may be a diminished amount of oxygen in the atmosphere, diminished carrying power of the blood, diminished lung capacity, or interference with the circulation of the blood.

The two factors which relate especially to diminished amount of oxygen in the atmosphere are bad ventilation

and altitude. The main effect of bad ventilation, especially where there are a number of people in a room, is to increase the humidity. The detrimental effect of this humidity, which will be considered at greater length later in this paper, is of more importance than any diminishing of oxygen or increase in carbon dioxide.

From diminished oxygen, altitude produces fatigue. Anyone who has climbed a mountain has felt this.

In industry we are more concerned, however, with the diminished oxygen carrying power of the blood. As before stated, oxygen is carried to the tissues by the blood, which also carries carbon dioxide from the tissues to the lungs to be eliminated.

There is a great difference in people as to the number of red corpuscles in the blood, and therefore in its oxygen-carrying power. Some people have only half as many red corpuscles as others. If these red corpuscles are much diminished the condition is called anæmia. Leaving out the question of loss of blood, anæmia is produced by a variety of causes, among which are deficient light, insufficient iron in the blood, insufficient variety of food, irregularity of the bowels, as the sequel of disease (particularly infectious disease) and of metal poison, such as lead. So, working at night, or in dark buildings or dark rooms, is injurious to the blood.

Carbon Monoxide.

A matter of particular importance to those in the iron and steel industry is the fact that the oxygen-carrying power of the blood is very much diminished if there is any carbon monoxide in the air breathed by the men. The deleterious effect of this gas is due to its combination with the red material in the blood, thus injuring the oxygen-carrying function. The affinity of the red material of the blood for carbon monoxide is much greater than its affinity for oxygen, forming a compound with carbon which is a much more stable compound than that formed with oxygen.

Carbon monoxide often produces a fatal effect. So we must guard against poisoning by this gas. This is a product of the furnaces and is especially dangerous in bad weather,

coming down the side of the furnaces. It also occurs in engine rooms from leaky gas engines; and we find it in plants where open fires, such as salamanders, are used for heating purposes in winter, or from blacksmiths' fires. Even though the quantities breathed are small this gas, breathed constantly, will in time produce anæmia. So gas engines should be watched. For heating purposes other methods than open fires should be adopted. And blacksmiths' fires should be hooded to carry away gases.

Anything that interferes with the general circulation of the blood, such as heart disease, tight clothing or the condition of the body, causes fatigue. Where there is diminished lung capacity, as in consumption of the lungs (phthisis), there is interference with the oxygen carrying power of the blood. In heart disease the blood is not properly pumped through the body. In the case of obese persons the increase of the vessels and the distance for the blood to travel make the heart pump harder. Tight clothing directly interferes with the circulation. All these cause fatigue. Age, sex, climate and seasons also have much to do with the circulation of the blood, and therefore with fatigue.

Accumulation of Waste Causes Fatigue.

The third great cause of fatigue is poisoning by accumulated waste in the muscles or poisoning by toxic substances. This accumulation may be due to too rapid formation of the products of waste, or it may be due to the inability of the blood or system to carry away the waste products. If the nerve of a muscle is constantly stimulated, the muscular contractions become smaller in extent and finally cease. The muscle is then said to be fatigued. The sugars and glycogen have been burned, producing energy and leaving as wastes carbon dioxide and lactic acid. Unless eliminated these materials act as poisons.

When a muscle is fatigued there is more, however, to be considered than the local poison. The products of fatigue pass into the blood and poison all parts of the body, including the nervous system. The question has been carefully studied by a number of able and well-known in-

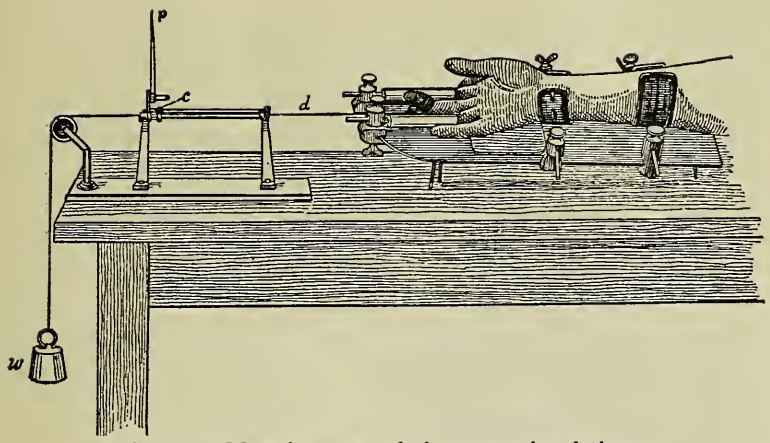

Fig. 1.—Mosso's ergograph for measuring fatigue.
(Courtesy of G. P. Putnam's Sons.)

vestigators. Special mention should be made, in the chronological order of their investigations, of those by Ranke and Helmholtz and Mosso and those by Professor Lee of Columbia University, whose more recent investigations have shed much light upon the intricate problems connected with this subject.

It has been shown by Mosso, late professor of physiology in the University of Turin, that the introduction of the blood of a fatigued animal into the circulation of one not fatigued will give rise to all the symptoms of fatigue in the normal animal. Mosso devised an instrument called the ergo-

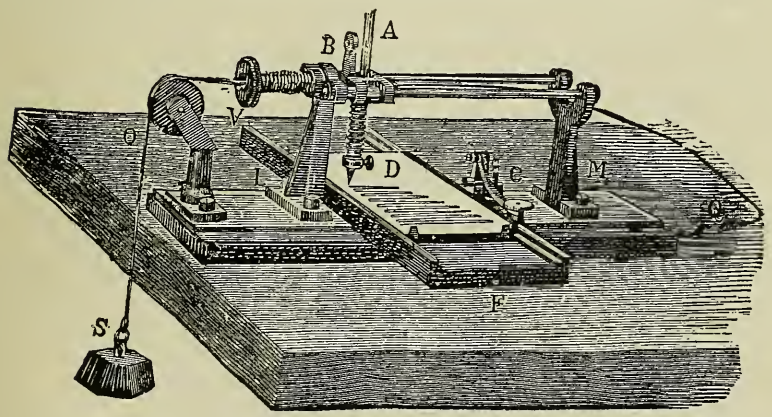

Fig. 2.—The registering runner of the ergograph.
(Courtesy of G. P. Putnam's Sons.)

graph. (See Figures 1 and 2.) In this instrument the arm, the hand and all the fingers but one are held, and the free finger rapidly lifts a weight over a pulley. A marker moving over a smoked surface registers the height to which it is raised. Experiments carried on in these ways show that the state of the brain, the central nervous system, as well as the

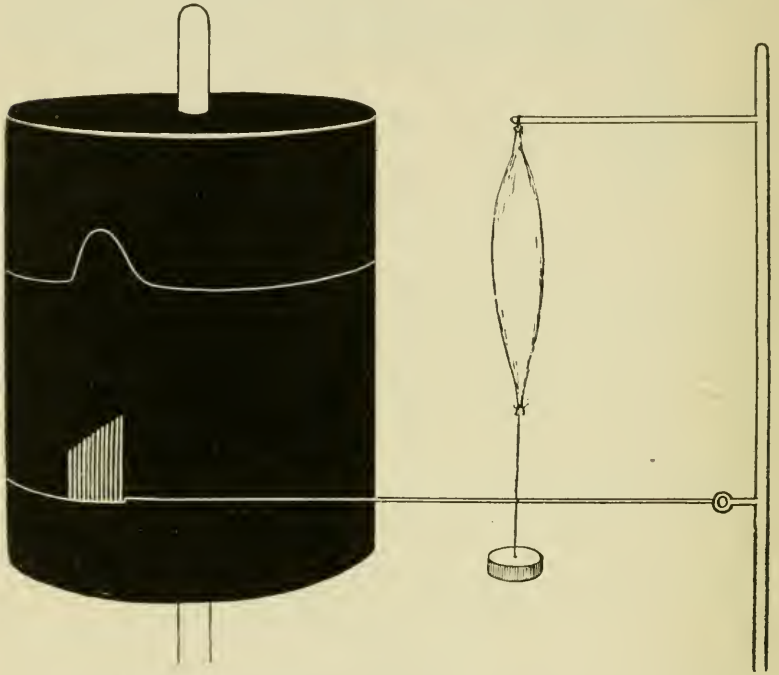

Fig. 3.—Apparatus for registering contractions of electrically stimulated muscle. (*Courtesy of Professor F. S. Lee.*)

condition of the muscles, are important factors in fatigue. The poisons produced diminish the power to send out nervous impulses.

Experiments on muscles removed from animals and stimulated by an electric current are also made and the results are recorded. (See Figure 3.)

Drinking of Water Lessens Fatigue.

Perhaps no means of lessening fatigue is of more importance than a proper supply of drinking water. The

products of waste, carbon dioxide and lactic acid, are taken up by the fluids of the body and carried to the lungs and kidneys for elimination. The accumulation of waste products is often due to insufficient use of drinking water. It has been noticed in the army that the man who falls from heat stroke is the one whose canteen is empty.

Poisons that are very dilute have as a rule but little detrimental effect upon the system. The most powerful acids if sufficiently diluted with water are no longer caustic. And self-generated poison in the body will, if sufficiently diluted, probably have less effect.

Some years ago in my service at Fordham Hospital, a number of cases of typhoid fever under my direction were given an average of 120 cubic centigrams of a normal salt solution in a vein. The effect almost invariably was to reduce the temperature of the patient to normal; and patients so treated progressed, as a rule, favorably toward recovery.

It would seem reasonable to suppose that the beneficial effects of the saline solution were produced in two ways: first, by dilution of the poison; second, by increased elimination by the skin and kidneys. The danger of destroying living cells and tissues by high temperature and by the toxin of typhoid was thus largely eliminated. This is one illustration of the importance of having in connection with every plant a proper water supply.

Some caution, however, is necessary. Water is not readily absorbed in the stomach but passes quickly into the intestines. If water is too cold, it is retained for a longer time in the stomach and its benefits are not so quickly felt. Sometimes if water is too cold it brings on cramps, and sometimes if too large a quantity is taken it is rejected. So the water supply for drinking purposes must not only be pure in quality and ample in quantity, but it must be kept at the proper temperature.

Cold Showers Lessen Fatigue.

Not only internally but also externally water plays a part in lessening fatigue. So the benefits derived from

general bathing should be mentioned. These have been recognized for many centuries, and the therapeutic use of the bath is as old as the art of medicine itself. The public baths of the Greeks and Romans were a prominent feature of their civilization. Recently hydrotherapy has received much study and has become more of a science. The

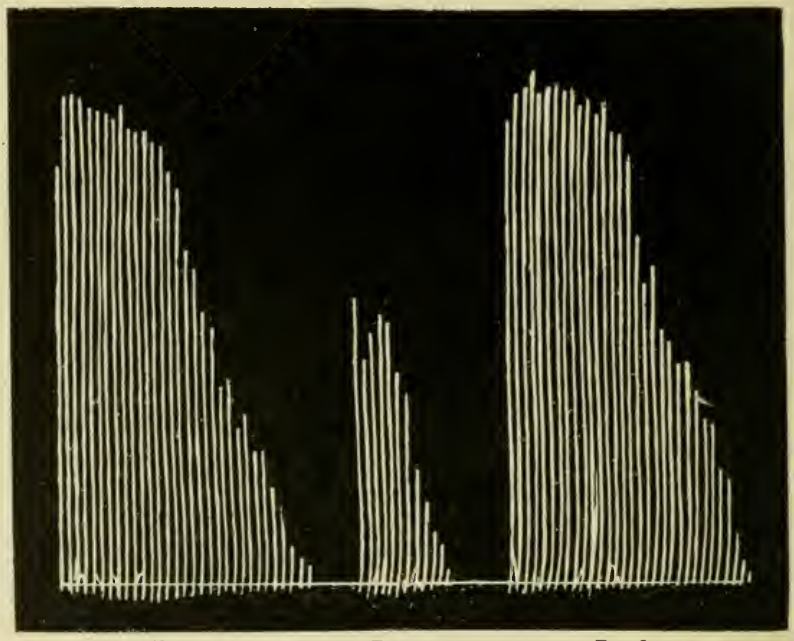

FIG. 4. FIG. 5. FIG. 6.

FIG. 4.—Normal fatigue curve. (After Vinaj.)
FIG. 5.—Fatigue curve of same after work.
FIG. 6.—Same after cold douche, showing restoration to normal.

capacity of water for heat makes it valuable for use in extracting heat or in applying heat.

As the skin covers a network of blood vessels and nerves, water can be used to affect a physical reaction.

In general, the application of cold causes the blood vessels to contract and heat causes them to dilate. Such stimulation of the skin affects not only the surface of the body but also the nerves and blood vessels of the whole system. And stimulation of certain areas of the skin affects directly certain internal organs. Such stimulation of the

skin influences both the voluntary and the involuntary muscles. Experiments upon the human body, recorded by the ergograph, have proven that in general cold applications increase resistance to fatigue and that they restore efficiency for work to a muscle already fatigued. (See Figures 4–8.) This increase in muscle tone produces a redistribution of the blood in the body. Conversely experiments show that a warm bath lessens efficiency. (See Figures 9 and 10.)

By means of shower baths the skin is mechanically stimulated by the striking drops. This combined with thermic influence increases the effect of the bath upon the heart and respiration. It also affects metabolism. It increases the production of animal heat. The heart action is increased in force. The secretion of the skin is diminished. It increases the urine and other internal secretions. Examination of the blood shows certain changes in the elements of

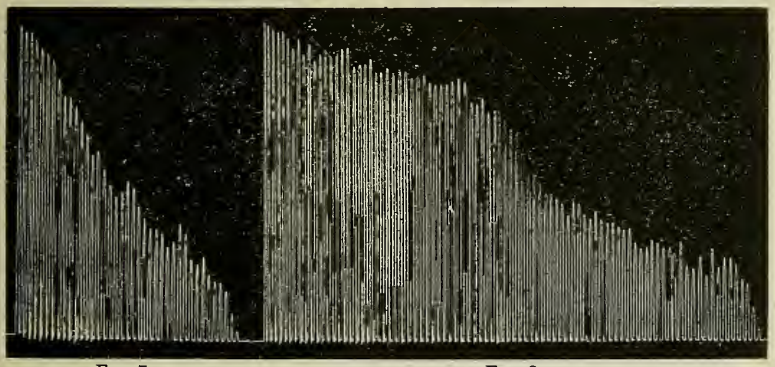

Fig. 7. Fig. 8.

Fig. 7.—Normal fatigue curve of the hand. (After Maggiora and Vinaj.)
Fig. 8.—Normal fatigue curve of the hand after a slowly cooled bath.

the blood itself. Thus water, through the skin, affects secretion, excretion and the heat regulating function.

Shower baths may, therefore, be used to eliminate more rapidly the products of waste, to promote secretion, to relieve fatigue, to restore the normal functions to various organs of the body, to restore the body temperature to the normal, and to produce a redistribution of the blood when there is congestion in any one part of the body.

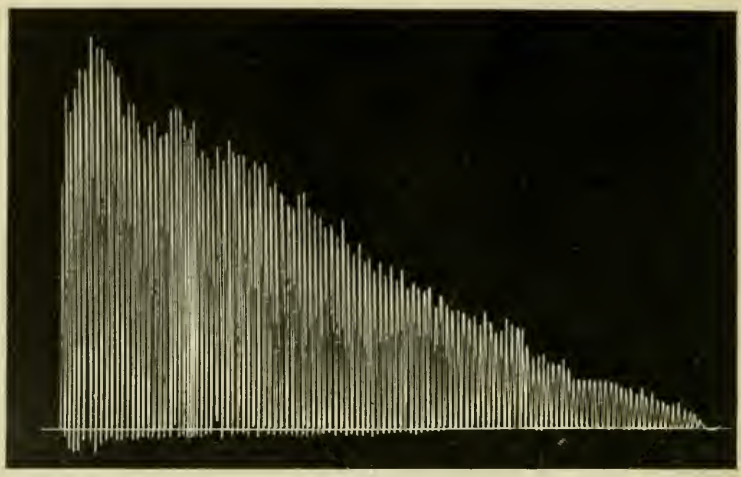

FIG. 9.—Normal fatigue curve.
(Courtesy of Dr. J. H. Kellogg.)

HEAT AND HUMIDITY AFFECT BODY TEMPERATURE.

Everyone knows that on a hot, humid day, a man is much less efficient than on a cool, dry day. The reason for this, however, has only recently been shown by scientific investigation. Ordinarily body temperature is maintained at a fixed level with but little deviation. The control of the production of heat and the regulation of its dissipation rest primarily in the brain and nervous system. On hot days when there is excessive humidity, the body temperature rises. Rise of temperature may occur in three ways: Heat produc-

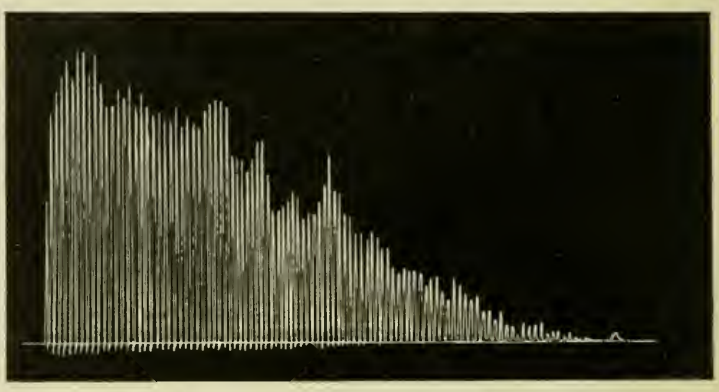

FIG. 10.—Fatigue curve, same subject, after a hot bath.
(Courtesy of Dr. J. H. Kellogg.)

tion may increase while heat loss remains constant, or heat production may remain constant while heat loss may be diminished, or heat production may increase while heat loss diminishes. There is increase of heat production after the absorption of a full meal. Muscular work also increases heat production enormously.

In general, heat production results from the combination of oxygen with carbon and hydrogen, forming carbon dioxide and water. In other words, oxidation is the source of heat production.

On exposure to external heat the blood vessels of the skin become dilated and the sweat glands become active.

By radiation, by conduction, and by the evaporation of water, there is loss of body heat from the skin. Heat is also lost by the moisture of the breath. When there is much humidity, sufficient to prevent evaporation of sweat and the elimination of the heat which is constantly being produced within the body, the internal temperature rises and fever results. The elimination of heat by the breath also depends somewhat on humidity. Dr. Denison, of Denver, has shown that fully eight ounces more water is lost by the breath during twenty-four hours in Denver than in New York. And according to my own experience and observation in Arizona, this amount is increased in that drier climate. Conversely, on a humid day we do not eliminate as much moisture by the lungs. Heavy clothes preventing evaporation from the skin increase this rise of temperature.

Observation of those who work in heat and excessive humidity shows that they soon pass into a condition of fatigue. That is, fever produces a condition of fatigue. This fatigue which comes from fever is brought about by the energy-forming materials in the muscles being burned up rapidly and the poisonous products of such combustion accumulating within the body. And, what is of great importance, if there is not a sufficient amount of carbohydrates for use there is destruction of protein material similar to that found in excessive work, due to the direct action of high temperature. In addition, the blood is drawn to the surface of the body, leaving the brain, the spinal cord, and the

internal organs correspondingly anæmic. This lessens the normal impulses to the muscles, and in itself will give a tired feeling.

Other poisons besides those generated in the muscles produce fatigue. Fermentations in the intestinal canal produce poisons which have a fatiguing effect. Thus indol, and possibly other substances, have been proven to induce fatigue. (See Figure 11.) Indol is a sulphurous compound found in the large intestine as the result of bacterial putrefaction. It is eliminated in part from the bowels; but is in part absorbed in the blood and subsequently eliminat

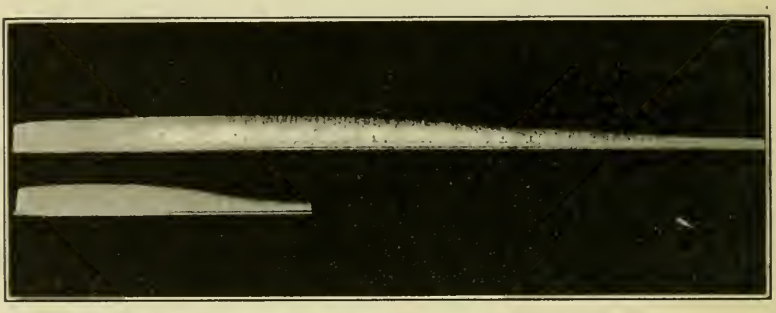

Fig. 11.—The upper record shows the normal fatigue curve of a muscle. The lower record shows the fatiguing effect of indol. (This illustration has never before been published and is shown here by the courtesy of Professor F. S. Lee.)

the urine, in the form of indican. As indol is produced by the fermentation of certain kinds of albuminous foods, diet is again an important factor. That the products of waste in the intestinal canal should be rapidly excreted is self-evident.

Other abnormal substances are sometimes formed in the digestive tract, such as B. oxybutyric acid and diacetic acid and oxalic acid, made from fats and carbohydrates. These undoubtedly also bear upon the question of fatigue.

Effect of Lack of Sleep.

Sleep is the period of repair and growth, the time when the building up process exceeds the breaking down process. During sleep less carbon dioxide is eliminated and less oxygen

is absorbed. Experiments upon dogs show that if starved even for several weeks they will recover, but that they die from loss of sleep in five days. Loss of sleep is much more damaging than starvation. Loss of sleep is a common cause of fatigue.

Thus badly ventilated rooms, and over-heated rooms in summer, crowding of rooms, with noise and other discomforts, and the hours of sleep are matters requiring careful consideration by those who employ labor.

Fatigue Lessens Resistance to Disease.

One of the most important results of fatigue is that it lessens resistance to disease. It has been shown that after the death of an animal from fatigue the body undergoes rapid putrefaction. Clinical experience and experiments on animals (see Figure 12) have shown that people who are fatigued are much more subject to contagious and infectious diseases.

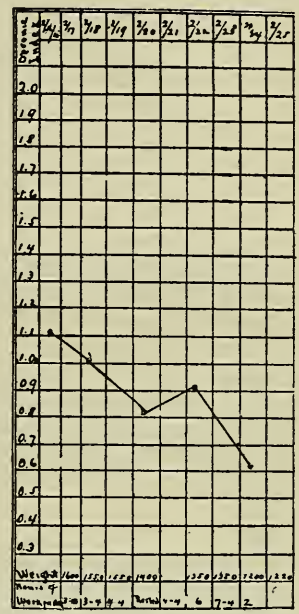

Fig. 12. — Opsonic index of a rabbit, showing lowered resistance to disease after fatigue. *(Courtesy of Professor F. S. Lee.)*

There is, therefore, a physiological, a chemical and a psychological basis of fatigue.

Conclusion.

If a muscle is fatigued from too rapid movement or from too long continued use, or if it is pushed in use when it is already fatigued, changes take place which affect the protein of the muscle and it is long in recuperating. After a double task, muscle requires four times as long as normal to recover. Work that is too hard and too long continued is harmful. Ambitious workmen doing piece work will sometimes produce this result by speeding beyond the limits which nature prescribes. (See Figure 13.)

But we must not charge to work what is properly chargeable to other causes. Ordinary tiredness resulting from proper effort is not harmful but beneficial, enabling us to enjoy and digest our food and obtain rest and recuperation from sleep. Work in itself is a joy and a blessing. It promotes longevity. As a rule people who work hard are not troubled with either indigestion or insomnia. Sound and true is the saying of Ecclesiastes, "The sleep of a labouring man is sweet, whether he eat little or much; but the abundance of the rich will not suffer him to sleep."

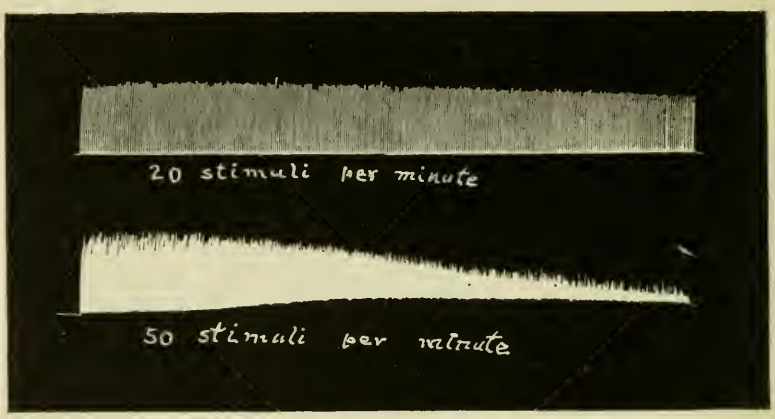

FIG. 13.—Curves showing that rapidity of work beyond a certain point quickly produces fatigue. (*Courtesy of Professor F. S. Lee.*)

Showerbaths and other methods of relieving fatigue should not be installed to spur men on to work when they ought to rest. Showerbaths are especially for use at the end of the day, to promote recuperation. They are, as a rule, not to be used during the day except under medical advice and direction.

The aim of employer and employee alike should be to do away with improper causes of fatigue, to the end that the workman may, in the interest of all concerned, do the best of which he is capable, thus growing in strength and in the power to achieve.

The conclusion is that both fatigue and efficiency depend upon the fundamentals of hygiene more than upon exercise alone, and that our aim should be, to use the words of

Professor Lee, "to make of labor a physiological rather than a pathological exercise." Thus shall we be able to obey the injunction of the apostle Paul: "Quit you like men; be strong." In the language of Maltbie Babcock,

> We are not here to play, to dream, to drift;
> We have hard work to do and loads to lift.
> Shun not the struggle; face it. 'Tis God's gift.

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